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Research paper

Electric Field Analysis and Experimental Study of Hybrid Lightning Protective Equipments

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Abstract

Background/Objectives: Lightning phenomena are increasing in frequency and intensity as industrial society develops. Therefore, each country enacts regulations and laws in consideration of environmental factors such as climate and topography and cultural factors.
Methods/Statistical analysis: We propose a hybrid method that combines two types of lightning protection facilities. The hybrid method is to protect the facility by installing a horizontal conductor in the ridge of the building and applying a leading streamer type lightning rod in the center.
Findings: Through testing and numerical analysis, the hybrid method showed excellent protection efficiency and economical efficiency. The electric field analysis was performed by comparing the horizontal conductor method, the lightning rod method and the HEC method, and the discharge current was measured and verified through experiments.
Improvements/Applications: The HEC method can be effectively applied to the lightning protection of modern buildings if it is used in parallel with the grounding equipment.

Keywords: *Horizontal conductor, Hybrid method, Lightning protection, Lightning rod, Steamer.*

1. Introduction

Lightning is a discharge phenomenon that occurs in the atmosphere, and the frequency of occurrence is increasing along with the weather phenomenon and the warming phenomenon. As a result, human damage as well as economic damage are increasing. It is required to install a more effective and efficient lightning damage preventive facility which has a safety factor due to direct and indirect damages caused by a lightning stroke. In Korea, the number of damage caused by lightning is not being effectively collected, and the number of damages and the amount of damages increase. It is necessary to accumulate quantitative data along with research on lightning discharge phenomenon by installing lightning protection facilities in the manner of protection of buildings against lightning[1,2].Also, it is necessary to examine whether the new lightning protection system is being used in accordance with the lightning protection equipment standard of its own country.

The purpose of the lightning protection facility is to eliminate the damage caused by lightning, which is increased according to various complex conditions. It also aims to prevent the direct or indirect damage of protected objects such as buildings and minimize the degree of damage. Lightning that occurs in the natural environment occurs in accordance with the region, season, geology and topography[3,4]. Therefore, detailed guidelines and regulations should be established in consideration of each climatic condition, geographical characteristic and cultural characteristic, and applied to buildings or facilities, and more efficient management is needed. Currently, there are regulations on lightning protection in Korea as well as various regulations related to lightning protection system such as buildings of Korea Industrial Standard. However, the standards of the brain protection facilities are set differently according to the protection target. The current KS C IEC 61024 (Korean Industrial Standard) is abolished in IEC 61024 and newly established and used as IEC 62305[5,6,7]. Currently, the abolished contents are applied and used in Korea. In addition, the International Electrotechnical Commission (IEC) addresses the systemic forms of design, maintenance, and management for lightning protection of protected objects in a comprehensive concept in lightning protection regulations[8].

Also, the development of industrial lighting technology does not mention technical criteria and evaluation methods of functional and performance characteristics due to the development of lightning protection facilities for lightning protection. When reviewing the regulations on lightning protection facilities in each country, it is a fact that it is aimed to improve the safety by focusing on the protection efficiency although there are slight differences. Lightning protection system, which is a protection efficiency centered lightning facility with improved safety, shall be applied effectively in design, construction, maintenance and management. In this paper, we propose a hybrid method to solve the problem of lightning protection method which is dependent on the existing Korean KS regulations, namely, difficulty in construction, lowering of protection efficiency, loss of economic efficiency. We hope that this information will serve as a valuable resource for redefining the criteria for a competitive and efficient lightning protection facility. Hybrid lightning protection equipment means that a corner of the ridge of a building is installed with a horizontal conductor and applying a protection angle to the outside[9].

The interior of the hybrid system adopts the leading streamer type lightning rod, and the electric field intensity is concentrated at the

corner portion, which helps to discharge the lightning current rapidly and forms a protection angle at any point of the horizontal conductor, thereby reducing the risk of lightning damage. The leading streamer type ESE(Early Streamer Emission) lightning rod applied inside is estimated to have a protection efficiency of 98%. At this time, the corona discharge current is increased due to the formation of an unequal electric field, and the effect of the traveling streamer advancing toward the thundercloud is activated have. In comparison with other samples, the hybrid method has proved that it is superior in terms of protection efficiency and economical efficiency through the horizontal conductor method, the mesh method, the ESE lightning method, and the hybrid type corona discharge current measurement comparative experiment[10,11,12].

2. Proposal of HEC Type

The HEC(Hybrid ESE and Conductor) method uses a horizontal conductor and a leading streamer type lightning rod. In other words, a horizontal line is provided for the ridge portion of the building, and a vertical line directed to the earth is provided around the vertex portion of each portion to induce a short formation of the discharge path. This is to facilitate the discharge of the brain current quickly and form a protective angle at any point of the horizontal conductor to reduce the fear of the side-brain damage. In addition, a leading streamer type lightning rod is installed from the peak projecting part of the building ridge, and the protection range is selected by the rotating spherical structure of the building below the installation side. In other words, the corner part of the ridge of the building is provided with a horizontal conductor, and a protection angle is applied to the outside of the ridge. The HEC method using the leading streamer type lightning rod efficiently constructs the lightning protection of the building.

The role of the lightning rod is to prevent the lightning damage of the buildings by arranging the lightning stroke point to be the location of the lightning stroke there. The evaluation of the performance of the lightning rod can be determined by the probability of induction of the lightning point, which depends on the ability of the down streamer to develop from the thunderstorm to the ground and the upward streamer to the thunderstorm on the ground. That is, the lightning collection capability is to evaluate the performance of the lightning rod. The streamer is developed by the field intensity of the ground induced by the thundercloud, and its progress distance captures and directs the down streamer directed to the lightning point, and the position of the lightning stroke is determined.

The performance of the lightning rod emits upward streamers toward the atmosphere, where the ability is related to plasma formation by neutral ions around it. The premise is due to the effect of the corona discharge, and the larger the discharge current due to the corona effect, the more advantageous it is. The corona discharge current is more advantageous than the corona discharge current generated in the lightning stroke because the ground electric field intensity is low at the beginning when the thundercloud approaches to the ground. The lightning point, usually determined by a lightning stroke, is determined at about 100 to 500 [m] above the ground. In this case, since it takes about 100-2,500 [us] to the lightning stroke point, the role of the corona discharge current generated in the early stage greatly influences the collection of the down streamer which determines the lightning point. The corona discharge current, which starts at a low field strength, increases steadily as the electric field rises. The corona discharge current is continuously and intermittently developed up to the plasma state to determine the upward streamer propagation distance.

3. Numerical Analysis of Electric Field

The analysis of electric field distribution according to air pollution method was performed only for qualitative analysis by finite element method. The analytical model was set to two dimensions and electric field analysis was performed by applying current of 10 [kV] to each model of each sample.

For the electric field analysis of lightning system, two dimensional finite element analysis is required. In this chapter, we derive the governing equations of electrostatic systems derived from Maxwell's equations. In the case of electrostatic field, since the phenomena of the system do not change with time, the field analysis is carried out by adopting the following from Maxwell's equations and auxiliary equations.

$$\nabla \times \vec{E} = 0 \tag{1}$$

$$\nabla \cdot \vec{D} = \rho_v \tag{2}$$

$$\vec{D} = \epsilon \vec{E} \tag{3}$$

Where E, D denote the electric field intensity and the electric flux density and ρ_v is the space charge density. The relation formula between electric field intensity and electric scalar potential is as follows.

$$\vec{E} = -\nabla\varphi \tag{4}$$

The electrostatic field governing equation of the form of the Poisson equation can be obtained by substituting equation (3) into equation (2).

$$-\nabla \cdot (\epsilon \nabla\varphi) = \rho_v \tag{5}$$

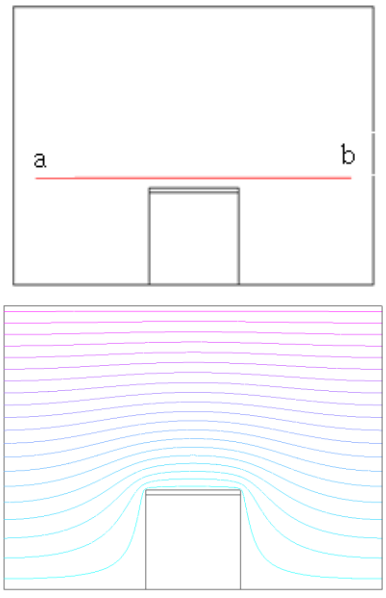
To apply the finite element method, the governing equations are expressed in the two-dimensional space as follows.

$$\frac{\partial}{\partial x}\left(\epsilon \frac{\partial \varphi}{dx}\right) + \frac{\partial}{\partial y}\left(\epsilon \frac{\partial \varphi}{dy}\right) = -\rho_v \tag{6}$$

In the two-dimensional electrostatic field analysis, since the phenomenon of the system does not change with respect to the time and the z-axis, the electric potential and the electric field intensity are as follows.

$$\varphi = \varphi(x, y) \tag{7}$$

$$\vec{E} = E_x(x, y)\,\widehat{a_x} + E_y(x, y)\,\widehat{a_y} \tag{8}$$



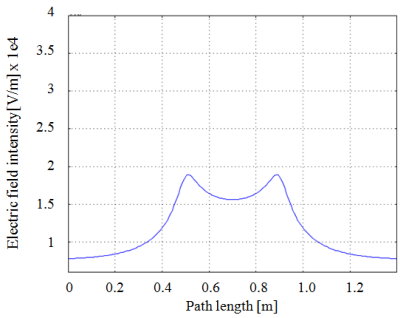


Figure 1: In case of Horizontal conductor type, the electric field extraction path and field intensity

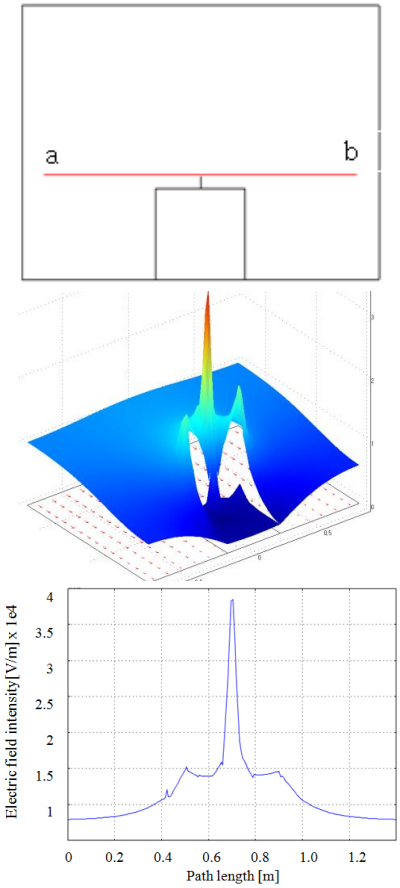
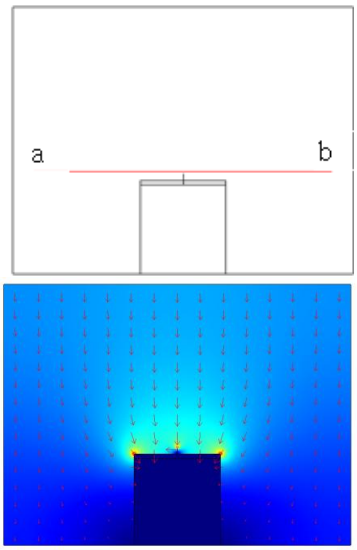


Figure 2: In case of ESE type, the electric field extraction path and field intensity



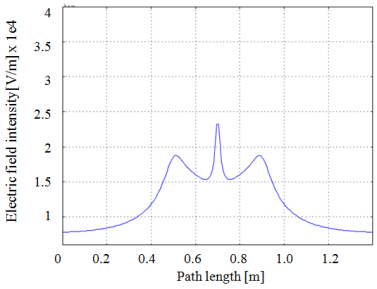


Figure 3: In case of HEC type, the electric field extraction path and field intensity

As shown in Figure 1, the horizontal conductor type has an electric field strength of 19 [kV/m] and the electric field distribution is strong on both sides of the building and relatively weak inside. As shown in Figure 2, the ESE type has a maximum electric field of 38.5 [kV/m], which is very strong at the lightning rod and very low at the outer side. As shown in Figure 3, the HEC type showed a strong electric field distribution and the electric field intensity was 23.5 [kV/m] on both sides of the lightning rod.

4. Experiment

In this section, we try to observe the point of time of the corona discharge current which changes according to the difference of electric field intensity by thundercloud through experiments. A model was constructed to evaluate the HEC method of air - termination for lightning protection of buildings. The model reduced the size of the building to 60m × 50m × 30m at a ratio of 60:1. The construction finish was covered with nonconductive paint instead of the usual concrete to prevent conductivity. The lightning rod is divided into horizontal conductor and lightning rod. The horizontal conductor is used as a diameter of 2[mm] instead of 95[mm^2] paddle and the leading streamer type is used for the lightning rod. Figure 4 is the installation diagram of high voltage generator and Figure 5 shows the reduced building models for experiment. In order to evaluate the characteristics of the air-termination for lightning protection, the experimental apparatus used in this study used a 400 [kV] high-voltage generator to apply the direct current high voltage of (-).In this experimental apparatus, the test voltage can be gradually and continuously adjusted using a variable voltage measuring device. Voltage and current waveforms were measured in real time on a notebook PC using the LABVIEW program.

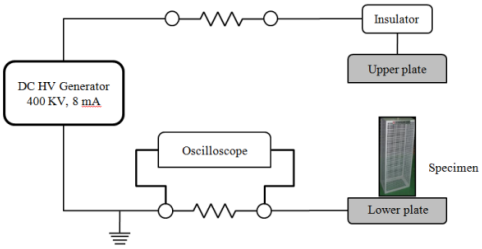


Figure 4: Installation map of high voltage generator

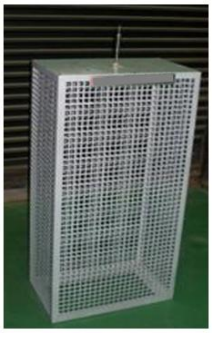


Figure 5: Reduced model

In order to study the HEC method for lightning protection, (-) DC voltage was applied to the upper circular plate and grounded to 0 potential at the air-termination part of the building corresponding to the lower electrode. The inter-electrode distance for measuring the corona discharge current was set to 80 [cm].The direct current high voltage was gradually increased with a variable voltage regulator and applied to the maximum voltage of 400 [kV]. The voltage division ratio for the voltage measurement was 1: 2000 and the current measurement resistance was 100 [kΩ].The direct current high voltage was applied to the rectifier and the capacitor in a multi-stage manner, and the top plate was simulated for the thunderstorm by applying a negative DC voltage and the plate was used for the diameter of 3 [m].In simulating the approach of the thundercloud, the increase of the electric field intensity was applied by raising the voltage of the DC high voltage power supply. The samples were measured by measuring the corona discharge current generated by varying the voltage of the DC high voltage power supply by each type. Figure 6 shows an experimental model for each air-termination type.

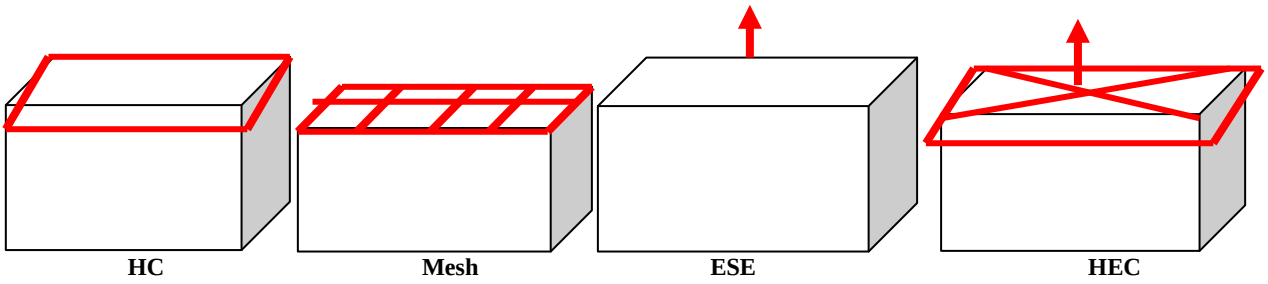


Figure 6: Various types of air termination for lightning

5. Results and Discussion

The HEC method for the lightning protection of buildings emphasizes the protection efficiency, economical efficiency and manageability for the protection of buildings, and also emphasizes on the corona discharge current according to the sample in each experiment of the experimental apparatus, respectively. The horizontal conductor type is the most widely used type, and it can be seen that the state of the corona discharge current generated in the horizontal conductor of the air termination starts at 200 [kV/m] when approaching thundercloud

Increasing the corona discharge current means ionization that occurs in the horizontal conductor with respect to the increase of the electric field intensity which changes with the thundercloud. This is a series of processes in which the progress of the streamer downward from the thundercloud to the earth and the lightning discharge occurs as the corona discharge current generated in the horizontal conductor develops as an upward streamer directed to the thundercloud. The steady increase in ionization facilitates the induction of lightning strikes and serves as a planned lightning protection facility. At this time, the protection efficiency of the building is less than 80 [%], and the inside space of the roof of the building is excluded from the protection range, and there is a fear of lightning. The realistic construction cost ratio can be calculated by applying the electricity standard part of the Ministry of Construction and Transportation by converting the reduced model of the sample to 1: 1.

In the mesh type, the safety is increased in the protection of the side and the inner space of the roof of the building, and the cost of the lightning termination of the lightning system increases. However, it can be seen that the utilization of the space on the roof and the maintenance part are very unreasonable, and the difference in the corona discharge current is small. When the lightning rod of the building is applied to ESE lightning rod, the protection efficiency is estimated to be about 98 [%], and the corona discharge current at this time is increased more than the existing sample due to the formation of the unequal electric field. It can be seen that the corona discharge current increases from the field strength of 130 [kV/m], indicating that the effect of the upward streamer advancing toward thundercloud is activated. As the protection efficiency is maintained at 98 [%], the cost of the lightning arrester is low. In case of HEC type, corona discharge current is increased at electric field intensity of 140 [kV/m].At this time, the protection efficiency can be secured to 98 [%], and economic effect and safety can be ensured.

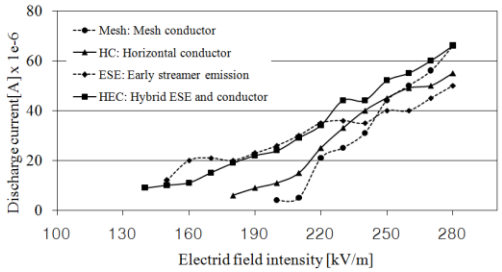


Figure 7: Magnification about various types of corona discharge current's increasing point

The HEC method proposed in this study is compared with the horizontal conductor method, the mesh conductor method, and the ESE method. Figure 7 shows that the corona discharging current is gradually increased at low electric field intensity by increasing the corona discharging current when the electric field is gradually changed.

6. Conclusion

In this paper, we propose a HEC method that combines the horizontal conductor method and the leading streamer emission method as a part to accept the lightning. It was experimentally investigated that the starting point of increase of the corona discharge current is low under the same protection efficiency condition, which is advantageous compared with other conventional methods in lightning protection. The field distribution was analyzed qualitatively by the finite element method to confirm the relationship between the shape of the air - termination and the starting point of the corona discharge current. The corona discharge current generates micro currents between the electrodes due to the applied electric field intensity. However, as the electric field intensity increases, insulation breakdown of the air occurs and the supply air is developed in the form of streamer by gas ionization. Experiments were conducted to examine the starting point of the corona discharge current, the electric field strength and the discharge current at the lightning stroke of each method, and it was possible to grasp the advantage of the early occurrence of the streamer and the probability of the lightning contact.

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